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All Sky Camera instrument for night sky monitoring

DUSAN MANDAT¹, MIROSLAV PECH¹, HRABOVSKY MIROSLAV¹, PETR SCHOVANEK¹, MIROSLAV PALATKA¹, PETR TRAVNICEK¹, MICHAEL PROUZA¹, JAN EBR¹,

¹ *Institute of Physics of Academy of Science of the Czech Republic, Czech Republic*

mandat@fzu.cz

Abstract: The All Sky Camera (ASC) was developed as an universal device for a monitoring of the night sky quality and night sky background measurement. ASC system consists of an astronomical CCD camera, a fish eye lens, a control computer and associated electronics. The measurement is carried out during astronomical twilight. The analysis results are the cloud fraction (the percentage of the sky covered by clouds), night sky brightness (in $\text{mag}/\text{arcsec}^2$) and light background in the field of view of the camera. The analysis of the cloud fraction is based on the astrometry (comparison to catalogue positions) of the observed stars.

Keywords: All sky camera, cloud detection, cloudiness, night sky monitoring

1 Introduction

An important issue of the night sky monitoring for High-Energy Astroparticle Detectors (HEAD) is the interaction of the monitoring instrument with the measurement of high energy cosmic ray particles. Contrary to lidars or radars that are active devices interfering at least to some extent with the HEAD data taking, the all sky cameras together with robotic telescopes or pyrometers are passive instruments that can work completely independently on HEAD. The benefit of all sky cameras is that the device works during the whole measurement period, it monitors atmosphere inside full HEAD Field Of View (FOV) and it does not influence the observation of high energy atmospheric showers. All sky cameras that are simple and cheap devices can be used to characterize immediate cloudiness, night sky brightness and their time variability not only at running experiments but also at candidate sites of future observatories [1]. On the other hand compared e.g. to lidars that deliver full atmospheric profiles of measured quantities (cloud heights, aerosol optical depth vs height), the all sky cameras cannot provide such a complex and detailed information.

This contribution focuses on basic hardware and data analysis principles related to all sky cameras. ASCs developed by Joint Laboratory of Optics of Palacky University and Institute of Physics ASCR in Olomouc are taken as an example.

1.1 System Description

The basis of the system is an astronomical camera G1 – 2000 (Moravian Instruments a.s., Czech Republic, www.mii.cz), which is equipped with a CCD chip ICX274AL by SONY company. The quantum efficiency of the CCD chip is higher than 50% at 450–550 nm and its spectral sensitivity covers the range from approximately 400 to 900 nm. The electronics has low read-out noise, a 16-bit analog-digital converter and a resolution of 1600×1200 pixels. The camera is equipped with a fish-eye varifocal lens (the field of view is 185 degrees) and an electronic controlled iris. This setup is capable of detecting a star with visual magnitude up to 6 mag in zenith.

A miniPC computer with USB I/O controls the system and processes the data. The I/O card controls the iris and the power switch of the camera. All electronics and a camera

body (see Figure 1) are weatherproof. The system power could be supplied by a solar power system or local power line. The switching electronics turns the system ON after sunset and keeps it going during astronomical night. The system is OFF during the day (to save energy). Temperature of the electronics is controlled and stabilized using internal heating system during winter time to protect the ASC system.

1.2 Calibration of the field of view

The fish-eye varifocal lens has 185° FOV and its aberration distorts the image. The correct transformation of the incident angle to the imaged pixel position is very important. The mechanism of the calibration is as follows: the light source (a spot as small as possible) is placed at a defined distance (at least 10 m), then the body of camera is rotated around the axis such that the incident light angle (corresponding to the FOV angle) varies between 0 and 90 degrees. The position of the light spot is analyzed for each angular step. This procedure is repeated for different plane cuts of the lens FOV. The final data are analyzed and fitted with a polynomial function. This calibration is regularly checked on-site by comparing the position of detected stars with the stars in a catalog. On-site measurements are also used to determine the variation of the sensitivity of the system with the zenith angle.

1.3 Night sky data taking and principles of analysis

The ASC system takes full sky images periodically in predefined moments (time period is limited by $2 \times$ exposure time - night sky image and dark image). Examples of clear and partly cloudy night sky are shown in Figure 2.

The measurement process consists of the following steps. Initially, every exposure of a night sky is followed by a dark frame image so that subtraction of one from the other enables significant reduction of noise in the image. The horizontal coordinates of each image pixel are then calculated with the calibration data and calibration constants used to determine the horizontal coordinates, azimuth and elevation of each image pixel. The total charge of each pixel is proportional to the light intensity, but the intensity

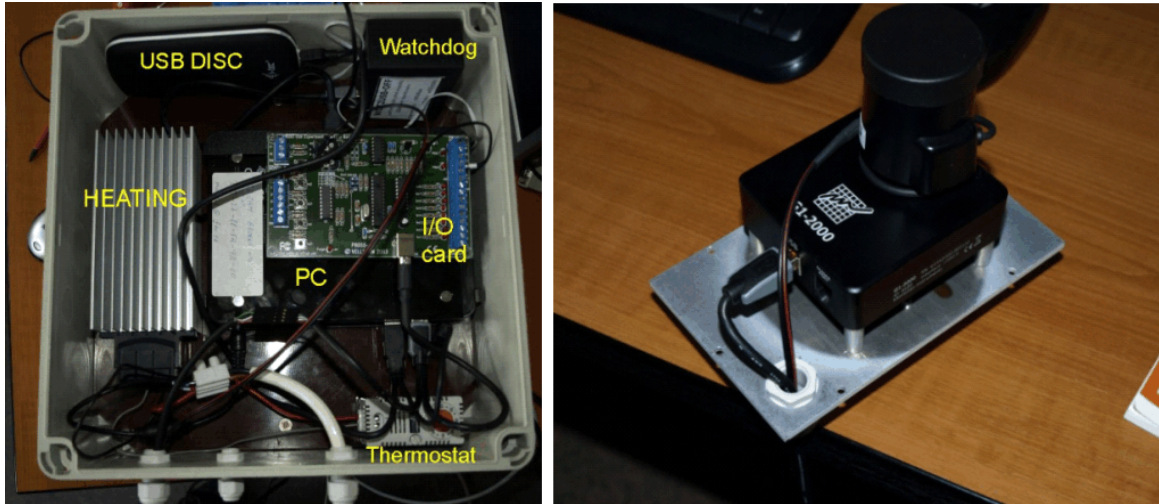


Figure 1: Electronics and the inside of the camera box.

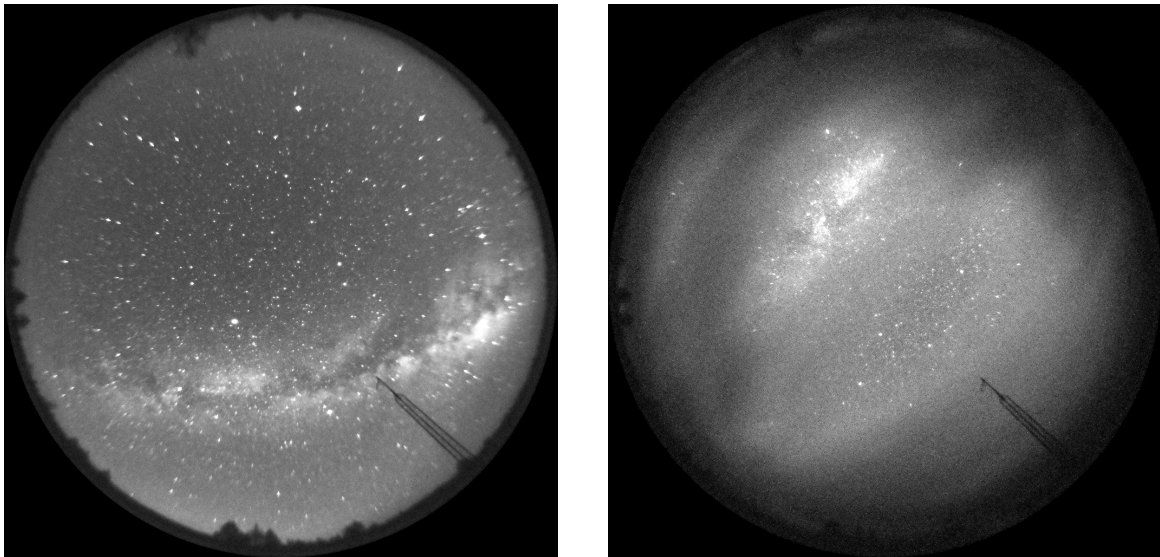


Figure 2: Left: Image of clear night sky. Right: Partly cloudy night skies. Moon and clouds are visible close to horizon.

of the final image varies with respect to zenith angle due to vignetting and distortion of the lens. The calibration of this zenith angle intensity dependence is obtained by considering extinction in air masses, optical distortions and vignetting variation as a function of zenith angle. The resulting attenuation at, for example, 60 degrees zenith angle corresponds to 4 mag (see Fig. 3).

To estimate the cloud fraction, we investigate the presence of stars in the field of view of the camera. We separate the full sky to approximately 70 segments and analyze each segment of the sky individually to obtain the cloudiness. As a star catalog we use Yale Bright Star Catalog BSC5 [2], particularly the visual magnitudes of the stars. First we estimate the position of each segment on the sky using the data from the calibration. This information is then further improved using the brightest stars from the catalog in each segment. Once the position of a segment on the sky is fixed, the stars for the segment are read from the catalog and selected according to the expected sensitivity at the given zenith angle. For every star in the catalog, we look

for a detected star within the angular limit of 1° . If a star that fits this criteria is found, then the catalog and detected stars are flagged as paired. Figure 5 shows a result from cloudiness analysis of partly cloudy night sky. The ratio of paired / unpaired stars (for all segments) gives final cloudiness of the night sky. Typically, we check about 500 catalog stars for the whole observed sky (up to 60° due to high distortion close to horizon). The error of the algorithm was calculated using artificial cloud simulations (Fig. 4) and the total uncertainties of the cloudiness calculation are 2% for cloudiness $< 20\%$ and 5% for cloudiness $> 80\%$. The cloudiness of the night sky is computed up to the maximal zenith angle with 10° steps.

Brightness of the night sky could be evaluated directly from a light flux. The system has been calibrated using a darkness sky measurement tool Unihedron SQM-LE [3]. The night sky was scanned overnight and recorded data both from the camera and SQM instrument were compared to each other. Subsequently the conversion formula is

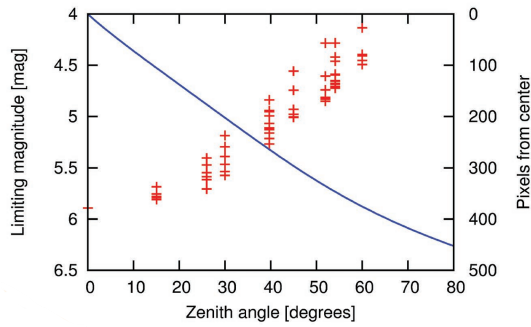


Figure 3: Zenith angle to magnitude dependence. The red points show sensitivity thresholds in different azimuthal angles as a function of the zenith angle. The blue line is the geometric calibration - distortion description.

obtained. The data represent the brightness of the night sky in $\text{mag}/\text{arcsec}^2$ and in visible light spectrum.

1.4 Limits of the cloudiness analysis

The measurement using the ASC is limited by local weather conditions, camera misting and Moon position. The local weather limitations mean for example rain or snow, fog, haze and water condensation on the camera. Examples of rain, fog and snow are shown in Figure 6. The algorithm usually fails if the lens of the ASC is obscured in some way, for example by snow, water resulting from rain fall, haze or fog surrounding ASC, or even bird droppings from birds found locally. The presence of the Moon saturates the image and increases the background in the image, and consequently the algorithm for cloud detection could not be used at such times.

2 Conclusions

The ASC, its application and limits are presented. The result of the analysis is the night sky cloud cover and night sky brightness. The main advantage of the all-sky camera is that it is a fully autonomous and self-reliant tool which can be used to monitor the night sky in even the world's most remote places, which happen to be just the ones most promising for astronomically related applications. The autonomy of the camera significantly contributes to the extremely low cost for its operation. The costs involved are concentrated mainly in the deployment phase, namely the costs of the parts and assembly of the camera, shipping (varies depending on destination, the shippable weight being 10 kg) and installation (two people working for two or three days). As demonstrated in [1] the camera can operate without maintenance for months and years after installation. However, it is advantageous to have local support for the case of unexpected external hindrances, but in most cases, a nonspecialist local personnel is sufficient to fix most of the possible issues.

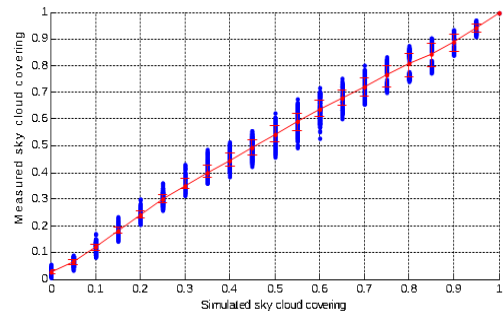


Figure 4: Error of the algorithm calculated using artificial cloud simulations with cloud fractions from 0% - 100% with step of 5%. Horizontal axis shows the simulated cloud cover and vertical axis corresponds to values calculated by the algorithm (blue dots). The error bars (red) represent the statistical estimation of the algorithm uncertainty.

projects LE13012, 7AMB12AR013 and LG13007

References

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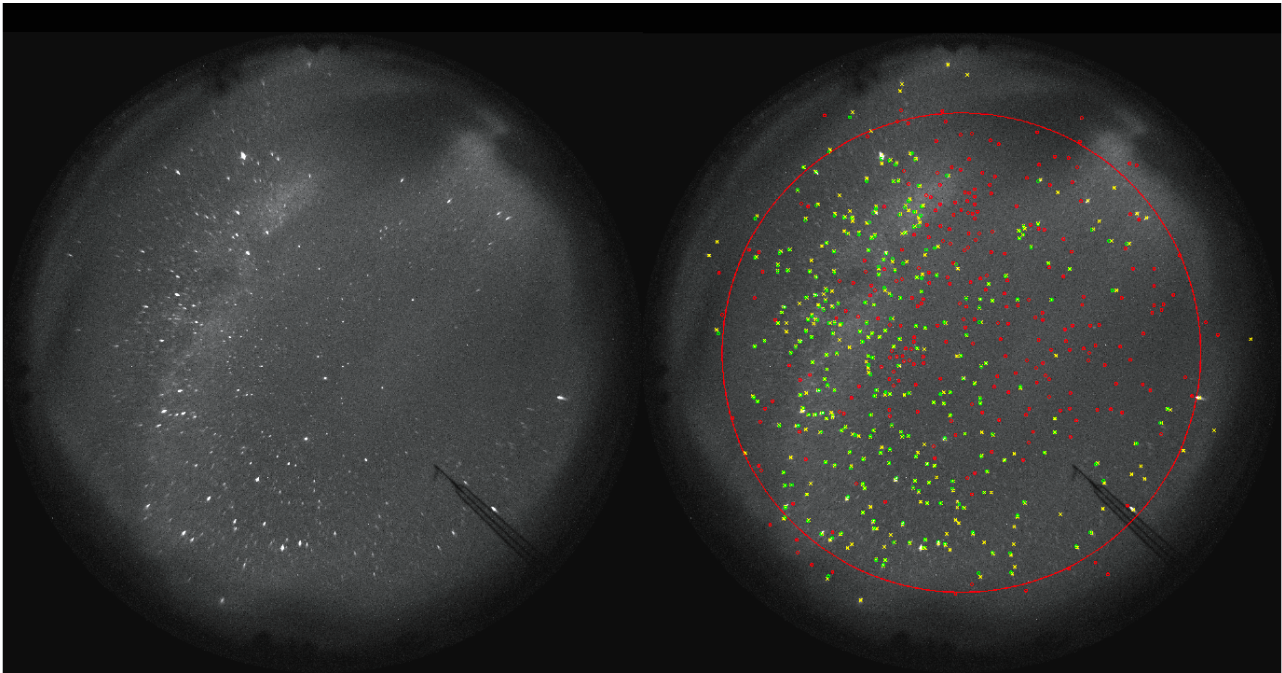


Figure 5: An example of analysis of partly cloudy night sky. The image on the left shows RAW image of the sky. The image on the right shows the analysis results, the yellow crosses indicate the detected stars, green circles catalog stars and red circles represent catalog stars without detected pairs - the region covered by cloudiness. The red circle indicates the limiting zenith angle (60°).

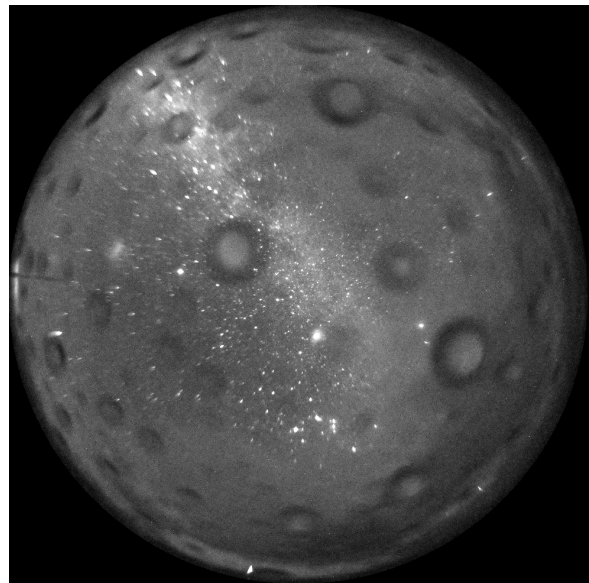
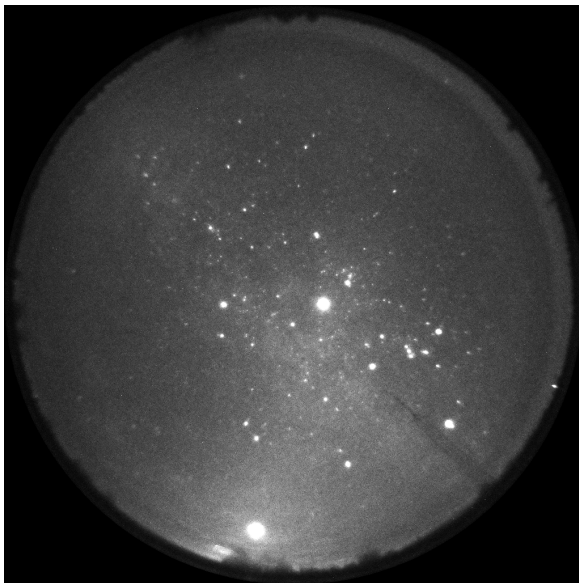


Figure 6: Left: Fog or haze affects the visibility of night sky, the nearby tower is not visible (the visibility fades with the fog/haze). Right: Lens of the ASC covered with water drops.